arXiv:1101.0756v1 [hep-ph] 4 Jan 2011

Tagged jets and jet reconstruction as a probe of the quark-gluon plasma

R.B. Neufeld

Los Alamos National Laboratory

Abstract

The large center-of-mass energies available to the heavy-ion program at the LHC and recent experimental advances at RHIC will enable QCD matter at very high temperatures and energy densities, that is, the quark-gluon plasma (QGP), to be probed in unprecedented ways. Fully-reconstructed inclusive jets and the away-side hadron showers associated with electroweak bosons, that is, tagged jets, are among these exciting new probes. Full jet reconstruction provides an experimental window into the mechanisms of quark and gluon dynamics in the QGP which is not accessible via leading particles and leading particle correlations. Theoretical advances in these exciting new fields of research can help resolve some of the most controversial points in heavy ion physics today such as the significance of the radiative, collisional and dissociative processes in the QGP and the applicability of strong versus weak coupling regimes to describe jet production and propagation. In this proceedings, I will present results on the production and subsequent suppression of high energy jets tagged with Z bosons in relativistic heavy-ion collisions at RHIC and LHC energies using the Gyulassy-Levai-Vitev (GLV) parton energy loss approach.

The observation of the suppression of energetic partons in the QGP, that is *jet quenching*, is one of the most important results from the heavy-ion program at RHIC [1, 2]. Experimental measurements thus far have mostly been restricted to leading particle suppression relative to $p + p$ collisions [3] because of the limited center-of-mass energies available. However, in order to constrain the underlying quantum chromodynamic (QCD) theory of jet quenching, new and more differential observables are needed. Leading particle suppression alone cannot discriminate between partonic energy loss formalisms or extract quantitatively the jet quenching properties of the QGP [4]. Particularly promising new observables are jets tagged with electromagnetic [5, 6] or weakly interacting probes and jet shapes [7, 8].

Tagged jets refer to high energy partons produced in association with the tagging particle. Because they have negligible medium induced modifications, electroweak bosons are ideal tags to study partonic energy loss. Within leading order (LO) kinematics, the tagging particle serves as an exact calibration of the initial associated jet energy. In this way, one hopes to obtain the amount and distribution of partonic energy loss by reconstructing the tagged jet. The leptonic final states of the Z^0 boson are an especially attractive jet tag because the large invariant mass of the Z^0 boson makes it easy to distinguish from the background generated in a heavy-ion collision. The heavy-ion program at the LHC will enable the experimental measurement of this feature for the first time.

As mentioned previously, at LO the kinematics ensure that the tagging Z^0 boson serves as an exact measure of the associated jet p_T (magnitude of momentum transverse to the beam line). This is on display in Fig. 1 where I present results [5] for jets associated with $Z^0/\gamma^* \to \mu^+\mu^-$ in p+p collisions at $\sqrt{s} = 4$ TeV. In the plot, the tagging Z^0/γ^* is required to have $7 < p_T < 13$ GeV and curves are presented for the leading and next-to-leading order (NLO) results, as well as for three different values of jet reconstruction radius, $R = \sqrt{(\Delta\phi)^2 + (\Delta y)^2}$. The NLO calculations are performed using the publicly available Monte Carlo for FeMtobarn processes (MCFM) developed by Campbell and Ellis [9]. In the figure, one indeed sees that at LO the Z^0/γ^* serves as an exact tag of the associated jet energy, as
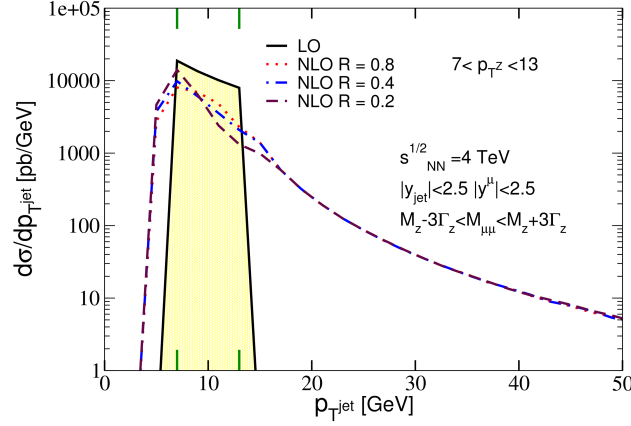
Figure 1: When going from LO to NLO, the tagging power of the Z^0 boson is compromised by the possibility of an extra jet in the final state, as seen from the figure. The LO result is constrained exactly by the p_T cut on the tagging particle. However, this is no longer true at NLO.

the jet p_T distribution is entirely inside of the tagging window of $7 - 13$ GeV. However, at NLO this correspondence is smeared due to the possibility of an extra jet in the final state. This relatively large smearing effect at NLO suggests great care must be taken in experimentally tagging the initial associated jet energy in AA collisions.

I next consider results for jets associated with $Z^0/\gamma^* \to \mu^+\mu^-$ in Pb+Pb collisions at $\sqrt{s} = 4$ TeV/nucleon pair. In this proceedings I will not consider cold nuclear matter effects [12], but will leave that for a future work. In Pb+Pb collisions it is essential to include medium-induced radiative jet energy loss. The partonic energy loss in medium for the results that follow was obtained from the Guylassy-Levai-Vitev (GLV) energy loss formalism [11]. The NLO results for tagging Z^0/γ^* required to have $7 < p_T < 13$ GeV is shown in Fig. 2 [5]. The result is shown for two

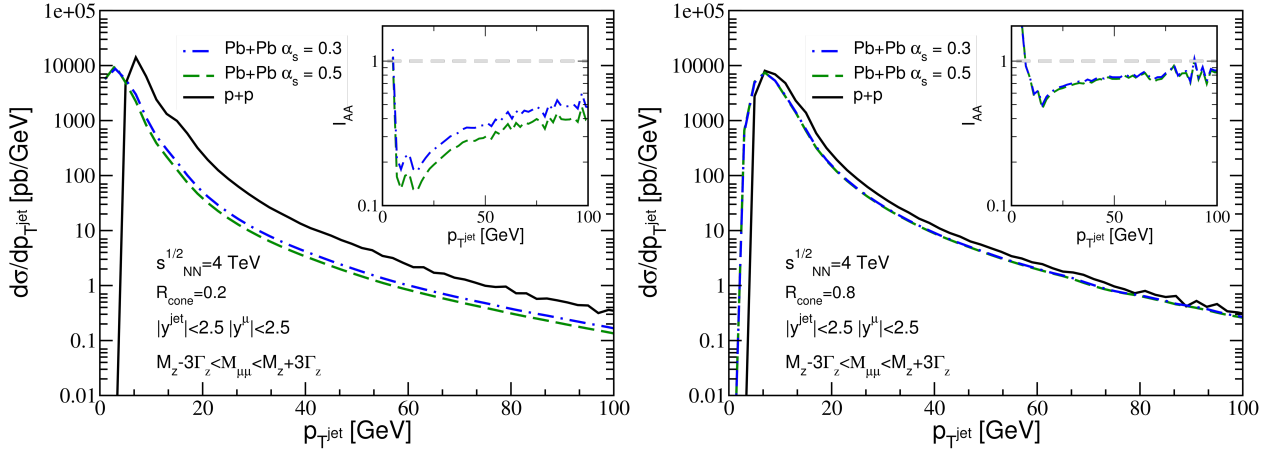Figure 2: The NLO p_T differential cross section per nucleon pair for jets tagged with $Z/\gamma^* \to \mu^+\mu^-$ in $p + p$ and $Pb + Pb$. The tagging Z/γ^* is required to have $7 < p_T < 13$ GeV. The results are shown for two different values of jet cone radius $R = 0.2$ (left panel) $R = 0.8$ (right panel). The medium induced energy loss shifts the curve to lower values of p_T. As the jet cone radius is increased, the medium modified curves approach the $p + p$ result, as more and more of the medium induced radiation is recovered in the jet.

different values of jet cone reconstruction radius, $R = 0.2, 0.8$ (left and right panel, respectively). The p_T differential cross section per nucleon pair for Pb+Pb is superimposed with the result from p+p which was shown in Fig. 1. It is clear from the figure that the effect of medium induced energy loss is to shift the curve to lower values of p_T. It is also clear that as the jet cone radius is increased, the medium modified curves approach the $p + p$ result, as more and more of the medium induced radiation is recovered in the jet. This occurs regardless of the strength of the medium coupling, α_s. As the jet cone radius is decreased, the sensitivity to α_s becomes more important, as less of the medium

induced radiation is recovered. This sensitivity of the result in Pb+Pb to jet cone radius is directly related to the angular distribution of the medium-induced radiation, which will be discussed further below.

Full jet reconstruction and jet shapes are also promising new observables to help constrain the underlying QCD theory of jet quenching, and in particular, to obtain an experimental handle on the large angle medium-induced radiation spectrum [10]. To understand why this is true, consider Fig. 3 from Ref. [7], which shows a schematic
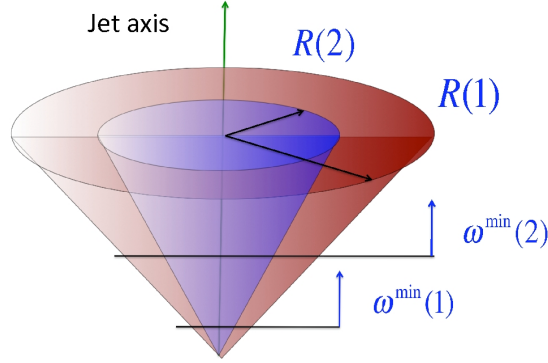

Figure 3: A schematic illustration of the jet reconstruction cone radius, $R = \sqrt{(\Delta\phi)^2 + (\Delta y)^2}$, and the particle tower energy selection, ω_{min}. As these parameters are varied, the amount of energy recovered in jet reconstruction (and hence the jet cross section) also varies.

illustration of the jet reconstruction cone radius, $R = \sqrt{(\Delta\phi)^2 + (\Delta y)^2}$, and the particle tower energy selection, ω_{min}. As one varies these parameters, the amount of energy recovered in jet reconstruction (and hence the jet cross section) likewise varies. This variation can be exploited to reveal the structure of the underlying medium induced radiation spectrum, as is demonstrated in Fig. 4, which is taken from Ref. [8]. The Figure shows predictions for the sensitivity
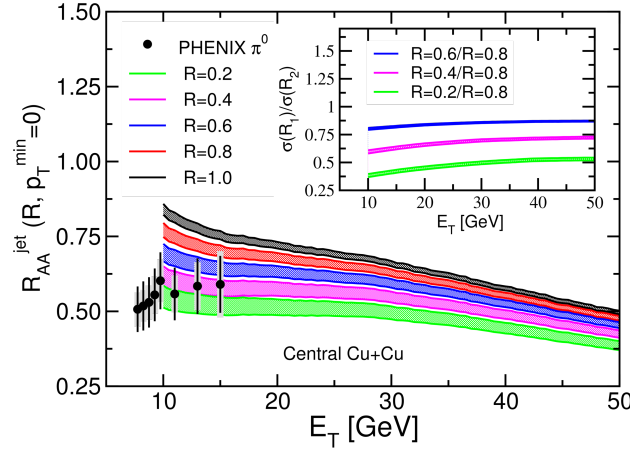

Figure 4: The figure gives predictions for jet R_{AA} as a function of jet reconstruction cone size $R = \sqrt{(\Delta\phi)^2 + (\Delta y)^2}$ using the GLV partonic energy loss formalism. The plot is for the most central Cu+Cu collisions at $\sqrt{s} = 200$ GeV per nucleon. The sensitivity of the suppression on cone size R reflects the angular distribution of medium-induced radiation. The insert shows the ratios of jet cross sections for selected values of R.

of jet R_{AA} on jet reconstruction cone size R using the GLV partonic energy loss formalism. The plot was done for the most central Cu+Cu collisions at $\sqrt{s} = 200$ GeV per nucleon. The dependence of the suppression on cone size R directly reflects the angular distribution of medium-induced radiation. The heavy-ion program at the LHC and the RHIC upgrades will enable a high statistics experimental measurement of this feature for the first time.

In summary, recent experimental advances at RHIC and the heavy-ion program at the LHC have ushered in a new era of experimental capabilities to probe the quark-gluon plasma. Among these new probes, jet shapes and jets tagged with weakly interacting probes are especially promising, particularly in light of the fact that leading particle suppression alone is not sufficient to discriminate between partonic energy loss formalisms or to extract quantitatively the jet quenching properties of the QGP.

I have here discussed the power of jet observables to reveal the spectrum of medium induced radiation and thereby shed light on the applicability of the commonly used energy loss formalisms. I presented results on the production and subsequent suppression of high energy jets tagged with Z bosons in relativistic heavy-ion collisions using the GLV parton energy loss approach. The results suggest that care must be applied in experimentally tagging the initial associated jet energy with electroweak bosons because of smearing due to higher order production processes. It is also observed that the dependence of the suppression in Pb+Pb relative to p+p on jet reconstruction radius R is a sensitive probe of the spectrum of medium induced radiation. I would here mention that tagged jets may provide an exciting opportunity to probe the medium response to hard partons [13], especially if the NLO smearing effects are brought under sufficient theoretical control.

Acknowledgements

References

[1] M. Gyulassy, I. Vitev, X. N. Wang and B. W. Zhang, arXiv:nucl-th/0302077.
[2] P. Jacobs and X. N. Wang, Prog. Part. Nucl. Phys. **54**, 443 (2005).
[3] S. S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **96**, 202301 (2006).
[4] S. A. Bass *et al.*, Phys. Rev. C **79**, 024901 (2009).
[5] R. B. Neufeld, I. Vitev and B. W. Zhang, arXiv:1006.2389 [hep-ph].
[6] D. K. Srivastava, C. Gale and T. C. Awes, Phys. Rev. C **67**, 054904 (2003); G. J. Kunde, H. van Hecke, K. Hessler and C. Mironov, Eur. Phys. J. C **61**, 785 (2009); I. P. Lokhtin, A. V. Sherstnev and A. M. Snigirev, Phys. Lett. B **599**, 260 (2004) [arXiv:hep-ph/0405049];
[7] I. Vitev, S. Wicks and B. W. Zhang, JHEP **0811**, 093 (2008).
[8] I. Vitev and B. W. Zhang, Phys. Rev. Lett. **104**, 132001 (2010).
[9] J. M. Campbell and R. K. Ellis, Phys. Rev. D **65**, 113007 (2002).
[10] I. Vitev, Phys. Lett. B **630**, 78 (2005).
[11] M. Gyulassy, P. Levai and I. Vitev, Phys. Rev. Lett. **85**, 5535 (2000);
[12] I. Vitev, Phys. Rev. C **75**, 064906 (2007).
[13] R. B. Neufeld, B. Muller and J. Ruppert, Phys. Rev. C **78**, 041901 (2008); R. B. Neufeld, Phys. Rev. D **78**, 085015 (2008); R. B. Neufeld, arXiv:1011.4979 [hep-ph].